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THE BEHAVIOR OF SMALL ANIMALS UNDER THE ACCELERATIVE CONDITIONS FOUND IN SPACE TRAVEL

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Research concerning living conditions in space and in spacecraft and concerning the interaction of man with these living conditions has been given considerable attention in recent years, and the results of this research have proven to have many useful applications with respect to conditions on earth.

In the United States, many faceted studies relating to this are being undertaken by various universities and research institutions, often with financial assistance from appropriate Government agencies. To give an idea of such studies in progress at the University of Kentucky, with the support of the National Aeronautics and Space Administration (NASA), two projects are here described briefly, dealing with the effect of mechanical forces which occur in flight or in space travel on the human organism, i.e., with the influence of accelerations (or lack of accelerations) transmitted from the flight vehicle to the passenger.

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It is first a matter of oscillating acceleration, namely mechanical oscillations characteristic of the rocket or set off by atmospheric factors and which are of relatively short duration and to be anticipated only during launch and reentry, and second of the long-term constant accelerations which the astronaut either entirely misses in the condition of weightlessness or which appear on other planets as positive or negative G.

Oscillating Accelerations

Human reactions to mechanical accelerations and shocks have been determined by years of experiment instigated by the U. S. Air Force Research Laboratories, under the direction of Dr. Rolf Coermann, in which experiments, test subjects were exposed in the laboratory to oscillating accelerations in various directions relative to the body axis, on oscillating tables and related apparatus. By measurement of the mechanical impedance, the body deformation, internal pressure in the

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intestine, visual acuity, working capacity and other physiological factors, it has been satisfactorily established that the human body has natural frequencies which, according to body build and position, occur mainly between 5-7 cycles and 11-16 cycles. The human being reacts with special intensity to oscillations in these frequencies, so naturally the more intensive the oscillation, the higher the amplitudes of acceleration.

The oscillation intensity to which the test subject can be exposed in such measurements are greatly limited by the circumstance that bodily injury must absolutely be avoided. At 5 cycles, for example, the three-minute tolerance of man to sinusoidal acceleration is only ± 1 G. For that reason, experiments at high amplitudes must be carried out with test animals (under anesthesia). Measurements in hogs show that the organism regarded as a mechanical system is not linear, but that an ordered nonlinearity exists which, if it proves true also for the human body, should make it possible to calculate the injury a human would suffer from very intensive oscillations and shocks rather than only measure it. /3

To complete the picture, the University of Kentucky is just now carrying out similar measurements with a series of animals, from mice to bears and chimpanzees (see Figure 1)[1]. In addition, a testing device is presently being developed under the direction of Dr. von Gierke of the U. S. Air Force, on which sinusoid or stochastic oscillations in all three directions and around all three axes can be produced simultaneously.

When a test object or subject is oscillated, the manner of fastening to the oscillating table is of importance, since the fastening system combines with the testing system to a new and complex oscillation system. For that reason, studies of strapping and protection systems are of great interest. In the case of experiments with vertical oscillations, gravity can usually be used for fastening, as long as the oscillation acceleration is small enough and the test animal or test person does not become separated from the oscillating table during the downward movement. At higher oscillation accelerations the animal must be strapped on or otherwise fastened. Figure 2 shows a rat in a tightly-fitted cylinder.

The film accompaning the lecture shows how the animal can be fitted perfectly into the cylinder by a body-enclosing cast of alginates, without small movements or respiration being impeded thereby. This

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[1] Note: Figures 1-4 and 8 could not be produced in the Tagungsberichte due to publication deadlines.

method increases the resistance of the test animal to oscillations and also its resistance to high rotation velocities around the longitudinal axes which occur in test rockets that are gyro-stabilized. In addition, by this method sensors for physiological measurements can be fastened easily and reliably to the animal. In contrast to purely mechanical oscillating systems, which can be calculated with relative ease, living beings have the ability to adjust their resilence and damping components and to change their mass distribution voluntarily or involuntarily. Thereby they change their natural frequencies and are accordingly in the position, within certain limits, of avoiding resonance with the effective oscillations. /4

It is important to learn to know these limits and therewith the adaptability of the living being to such oscillation conditions. The authors have therefore recently undertaken systematic experiments from which information in this respect is anticipated. Rats and small monkeys are given the opportunity to select the preferred combinations in oscillating fields that are graduated as to frequency and amplitude, and, by their behavior, to indicate what they tolerate and to what extent they can discriminate between the various oscillations. This research method requires close cooperation between physicists and engineers on the one hand and behavior psychologists and physiologists on the other, and in principle it is the same that has already been found fruitful in the gravitational acceleration studies described below.

Gravitational Accelerations

It is not yet quite known how man reacts to prolonged gravity conditions which differ from the familiar earth gravity. It may be that it is desirable and perhaps even necessary to create artificial gravity in the space vehicle. It may also be that man would prefer a very definite gravity between weightlessness and earth gravity. In order to obtain a first clue on this, the proposal has been made that an animal be sent into space for a long period in an apparatus in which it would be possible to seek through free choice any gravity between weightlessness and earth gravity. Assuming that a man would act similarly, it would then be possible to draw the desired conclusions from the behavior of the animal concerning preferred gravity for human beings. /5

Prolonged weightlessness can be created only in space, and the enormous cost of such flights makes it necessary that all preliminary work be carried out on earth in the laboratory. For that reason the immediate studies are limited to establishing first, in the gravity range of 1 G and upward, whether the animals actually have distinct preferance for certain gravities and whether they can be trained or

bred for other gravities. The observation technique developed in that connection will naturally benefit subsequent flights. The problem here was first to create a suitable artificial gravity field. The principle of the centrifuge is suited for this.

It was furthermore required that the animal should be able to move under its own power from one gravity to another, and for that reason it was desirable to form the test apparatus so that the floor everywhere would be at right angles to the force of gravity. Figure 3 shows that the earth acceleration and the centrifugal force required a paraboloid, and Figure 4 shows the ratio between velocity of rotation, radius and resultant acceleration. In addition to a preliminary test apparatus (which will not be discussed further here), a paraboloid was then constructed of glass fiber, which with a maximum diameter and height of 1 m each and a rotational speed of about one revolution per second had a field of from 1 G in the center to 3.2 G along the periphery.

In consideration of the final aim of sending a similar device into space, a small apparatus for small animals, namely mice, was created. This paraboloid is shown in Figure 5, at the bottom as seen from the side, and at the top as seen somewhat obliquely from above. It can be seen that the accelerations are marked by concentric circles at intervals of 3 m/s^2 and that a mouse at the moment is at 2 G. The animal can now move at the same acceleration level if it remains at the same radius, or it can cross the lines and thereby expose itself to other gravities. Food, especially raw potatoes, is available as a source of water on each gravity level so that individual animals can be placed in the field for observation for periods extending from 24 hours to one week. Observation extends to measuring what percentage of the time is spent in the various accelerations. The measuring is done in the following manner. A piece of cobalt-60 wire 3 mm long is fastened to the tail and the gamma radiation from this source is received by a scintillation counter visible under the paraboloid in Figure 5. These signals are recorded after amplification and integration, and continuously show the position of the test animals in the gravity field. The verification is done by the cobalt wire being carried from one gravity acceleration to the next. The first experiments were made with ordinary white and brown laboratory mice. In general, these animals moved during the first few hours as if hunting over the entire gravity field. Stroboscopic films, examples of which will be shown after this lecture, were used to determine whether the animals under the influence of the Coriolis effect caused by every radial motion component would let themselves be driven in spirals. This appears not to be the case, because the photographed paths are irregular and in both directions of rotation. It can be observed that the animals run, sit and lie normally at any G, but that standing up becomes a little difficult at 3 to 3.2 G.

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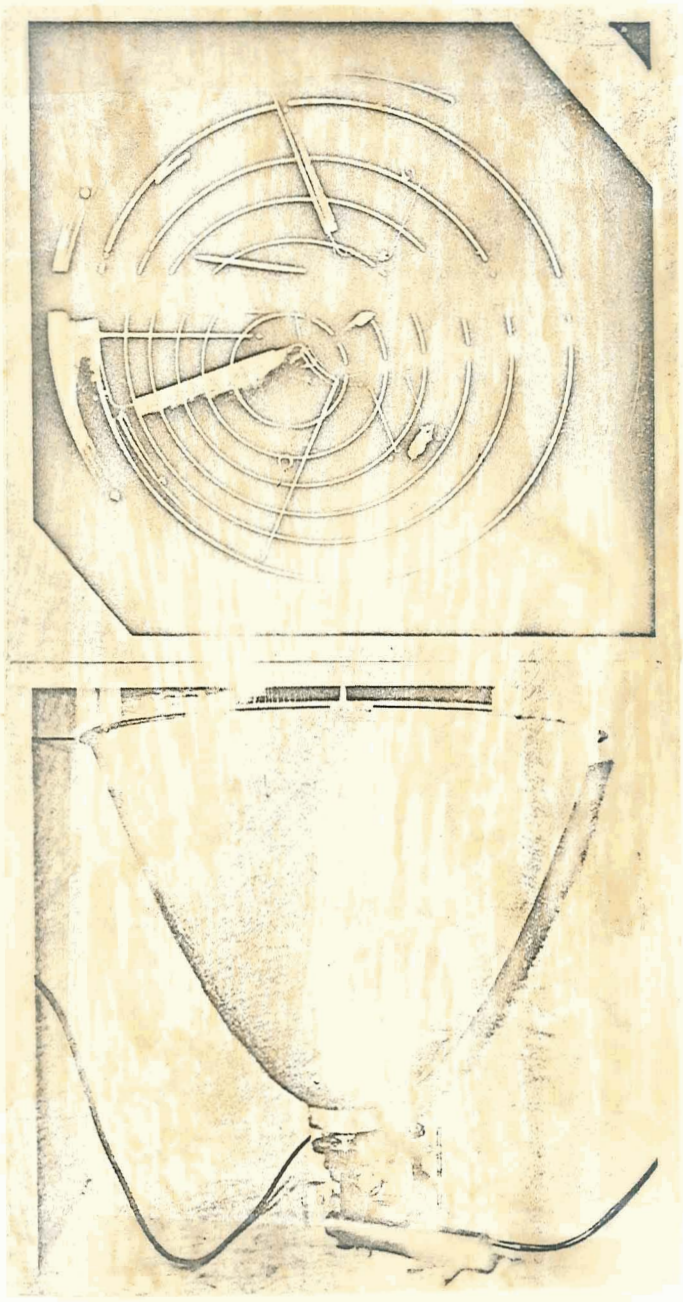

Figure 5. Paraboloid, furnishing a free choice gravity field of 1 G to 3.2 G to a mouse.

After a few hours the animals apparently learn that earth mice ought to live under earth gravity and spend about 85 percent of their time between 1 G and 1.3 G, but without giving up occasional and sometimes regular expeditions into the higher Gs while maintaining their systematic nightly activity. These animals then have the choice of living at gravities between earth gravity and super gravity. To permit making observations relating not only to accelerations, but also to a /7
higher normal gravity level, without going into space, an attempt was made at the same time to breed mice which for generations were accustomed to a higher gravity. For this the gravity of the planet Jupiter, 2.65 G, was selected and special breeding centrifuges were built for this gravity and were put into operation. As shown in Figure 6, they contain 8 individual boxes and are housed in rooms where there are other boxes with mice of the same age and type under the same environmental conditions, but under earth gravity. It was very soon found that while the "earth" mice multiplied according to plan, the "Jupiter" mice had difficulties. It was difficult even after birth to keep the young alive. At the present there exists a pair of Jupiter mice old enough to produce a second generation. Only when that has been accomplished will they be exposed to the gravity field in the paraboloid.

At the same time, mice were procured from another source and exposed to the gravity field. These animals suddenly showed an entirely different behavior. They preferred to remain for hours and days at the highest possible acceleration. Even when driven away from the high G level they sooner or later returned there. Experimental variations of all kinds were carried out without changing the fact that one kind of mice preferred the position near 1 G in the paraboloid, while the other wanted to weigh three times as much.

The results were not entirely unexpected. The authors from the beginning were aware of the fact that in a centrifuge not only centrifugal forces occur which combine with earth gravity to produce the artificial gravity, but that every radial movement and every angular acceleration releases lateral accelerations as shown in Figure 7. In the paraboloid such accelerations are not only produced by the locomotion of the animal, but by pure head motions. These accelerations have an effect on the sense of balance and lead to symptoms like those of seasickness. Such influences on test animals naturally depend on the position of the centrifuge and on the individual susceptibility and may be more vitally important than the gravity. Experience with test persons on centrifuges have shown that man is subject to the same symptoms. /8

The next objective must therefore be to examine both effects and, if possible, separate them from each other. That means, on the one hand, that the present method will be continued until enough material is on hand for statistical evaluation, and on the other hand, that further experiments will be undertaken by which the body position and

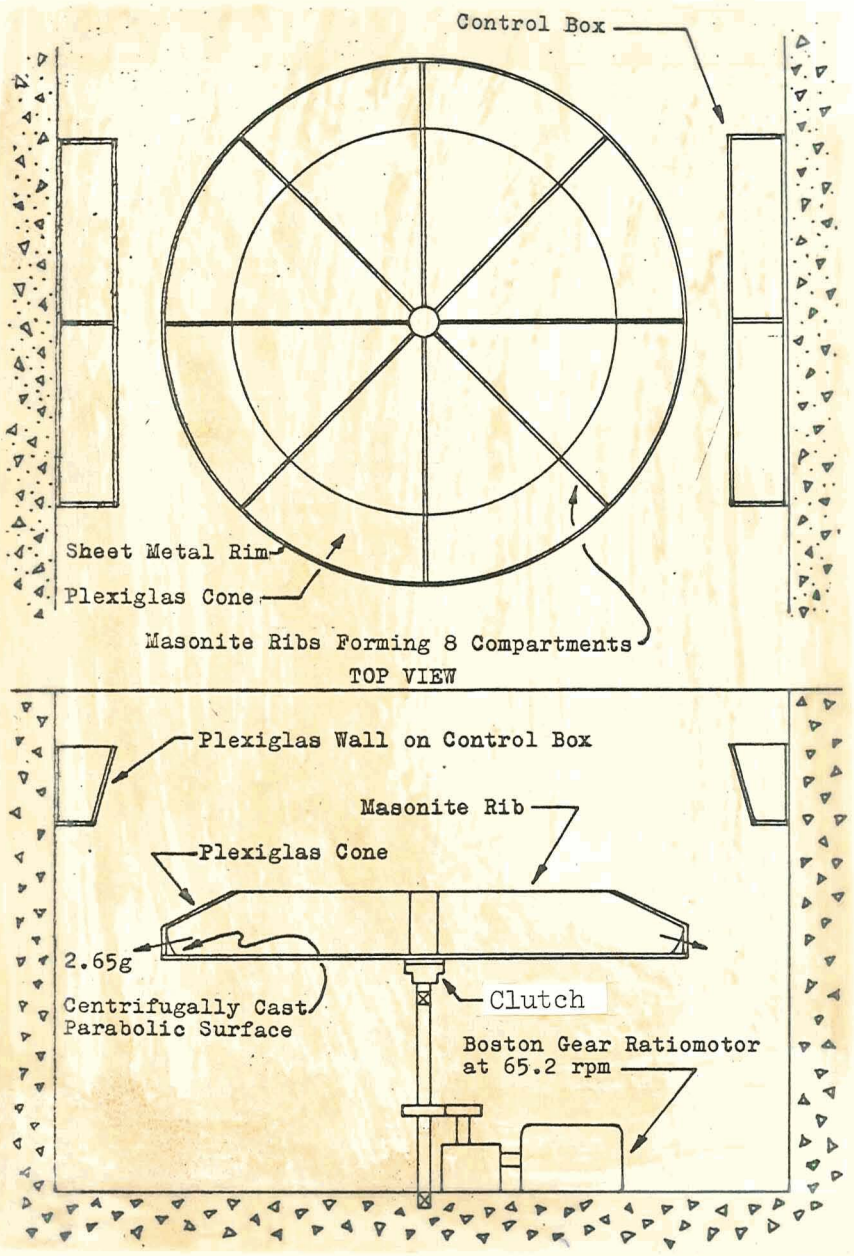

Figure 6. Centrifuge for breeding mice at 2.65 G's.

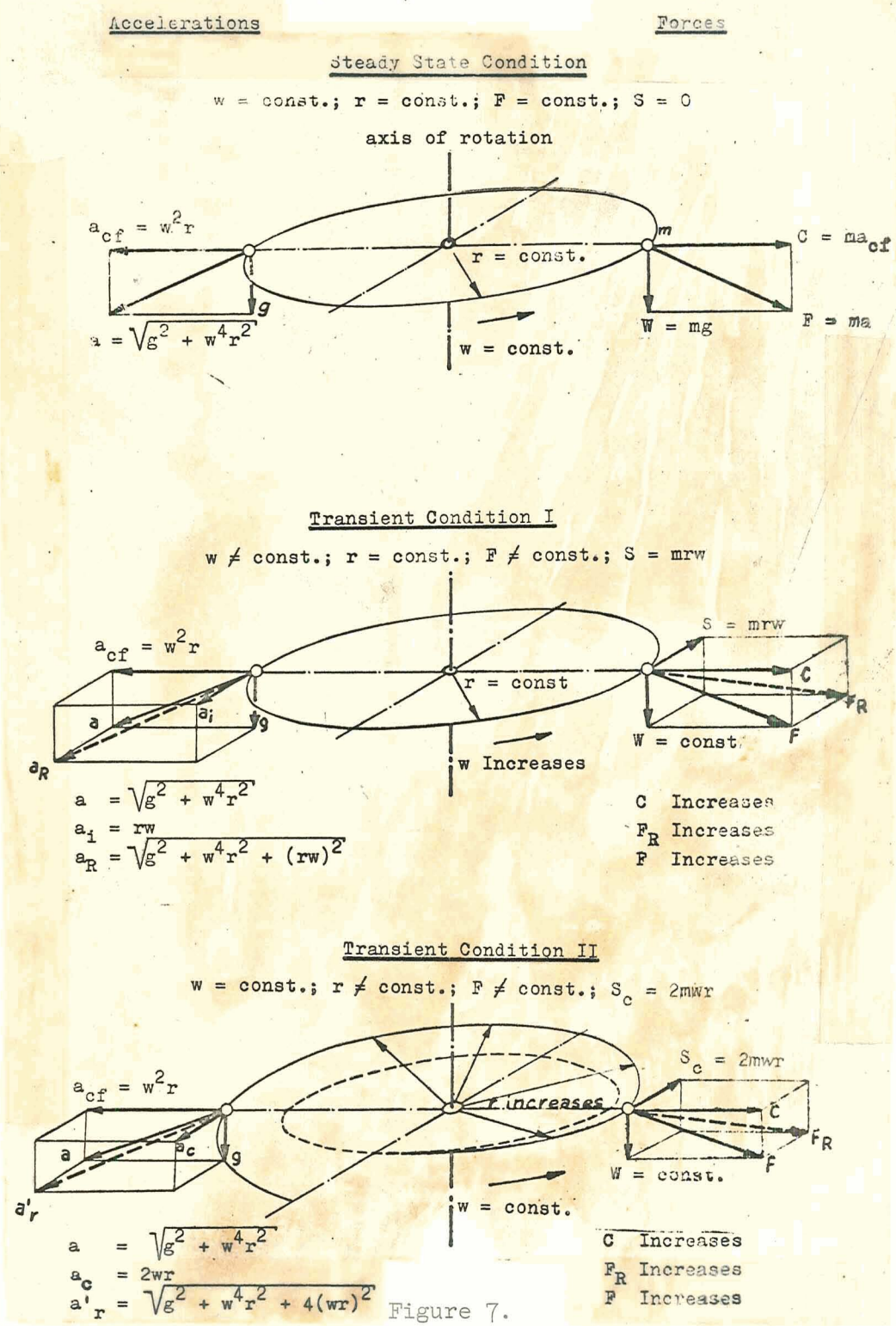
Accelerations
Forces
Steady State Condition
w = const.; r = const.; F = const.; S = 0
axis of rotation
$a_{cf} = w^2 r$
m
C = ma_{cf}
r = const.
g
$a = \sqrt{g^2 + w^4 r^2}$
W = mg
F = ma
w = const.
Transient Condition I
w ≠ const.; r = const.; F ≠ const.; S = mrw
$a_{cf} = w^2 r$
S = mrw
C
F_R
r = const
a
a_i
g
a_R
W = const.
F
w Increases
$a = \sqrt{g^2 + w^4 r^2}$
$a_i = rw$
$a_R = \sqrt{g^2 + w^4 r^2 + (rw)^2}$
C Increases
F_R Increases
F Increases
Transient Condition II
w = const.; r ≠ const.; F ≠ const.; $S_c = 2mwr$
$S_c = 2mwr$
$a_{cf} = w^2 r$
r increases
C
F_R
a
a_c
g
F
W = const.
a'_r
w = const.
$a = \sqrt{g^2 + w^4 r^2}$
$a_c = 2wr$
$a'_r = \sqrt{g^2 + w^4 r^2 + 4(wr)^2}$
C Increases
F_R Increases
F Increases

Figure 7.

animal's motion can be checked. A centrifuge is under construction in which the velocity of rotation and the radius can be programmed simultaneously and independently of each other, and small South American monkeys who themselves can operate these centrifuges will be the subjects of subsequent experiment (Figure 8).

Figure 1. A test animal during an oscillation experiment on the electro-hydraulic oscillating table of the University of Kentucky.
Figure 2. A test rat in a cylindrical container for oscillation and rotation experiment.
Figure 3. On the drawing.
Figure 4. On the drawing.
Figure 8. Small South American monkey, serving as test animal on the centrifuge.

Translated for the National Aeronautics and Space Administration by John F. Holman and Co. Inc.